

## **Thermal Remediation Processes for Removal of DNAPL in Fractured Media**

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Special difficulties are associated with the remediation of DNAPL contaminants from fractured media. We focus on a suite of common geological and contaminant site characteristics, which create especially challenging problems for many remediation technologies:

Depth of contamination greater than 5 or 10 meters;

Highly anisotropic flow networks;

Strong permeability contrasts, such as dead-end zones, regions associated with secondary fracture permeability or intrinsic wallrock permeability; and

Saturated media.

In such conditions, it may be advantageous to employ thermal remediation technologies, based on steam injection and vacuum extraction, and with possible augmentation through electrical heating. Such processes can volatilize and mobilize a large class of DNAPL contaminants for potential recovery. For thermal remediation techniques to be applied effectively in fractured media, particular design issues require special attention, including: Targeting specific permeability zones for injection of steam, and extraction of volatilized contaminants;

Imaging thermal variations during system operations for process control;

Adequate characterization for quantitative assessment of flow anisotropy and secondary permeability; and

Systematic manipulation of mass flux and gradients by controlling fluid injection and extraction patterns.

For example, placement of injection wells and screening intervals must work to drive mobilized contaminants to recovery wells. The fracture pathways through which volatilized DNAPL move may not be the same as the paths along which contaminants originally migrated. Accordingly, successful remediation must reverse the previous diffusion or dispersion of contaminants into secondary permeability (such as at dead-end fractures or within the wallrock of a sandstone). Mobilization of DNAPL in these locations requires that the mass surrounding dead-end sites is heated, or that thermal energy is introduced directly to the secondary permeability. In both cases, it is important to ensure that the thermal energy can be directed to provide heating of all targeted subsurface regions, and without remobilizing contaminants to areas below or outside the treatment zone.

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